SEARCH FOR CP-VIOLATION IN $K_S \to \pi^0\pi^0\pi^0$ DECAYS

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A search for CP-violation in $K_S \to \pi^0\pi^0\pi^0$ decays is performed using the data collected with a short neutral beam at the CERN SPS during the year 2000. New limits on the CP-violating parameter η_{000} and BR($K_S \to \pi^0\pi^0\pi^0$) are reported. Using the Bell-Steinberger unitarity relation, the error on the CP-violating and CPT-violating parameter Im δ is reduced leading to an improved test of CPT conservation: the difference between the K^0 and the $\overline{K}^0$ mass is found to be: $\Delta M = (-1.7 \pm 4.2)^{-19}$ GeV.

CP-Violation in $K^0 \to 2\pi$ decays is firmly established and the parameters which describe it ($\eta_\pm$, η_{00} and ϵ'/ϵ) are precisely measured [1–3]. CP-violation in $K_S \to 3\pi$ is equally allowed in the Standard Model (SM) but has been investigated in much less detail owing to the difficulty of the measurements. A $\pi^+\pi^-\pi^0$ state is mainly CP-odd while a $3\pi^0$ state is purely CP-odd. The equivalent of η_{00} for $K_S \to 3\pi^0$ decays is $\eta_{000} = A(K_S \to 3\pi^0)/A(K_L \to 3\pi^0)$. In the SM, $\eta_{000} = \epsilon + i\text{Im } a_1/\text{Re } a_1$, where a_1 is the isospin 1 amplitude for $K^0 \to \pi^0\pi^0\pi^0$ and $\epsilon = 2/3\eta_\pm + 1/3\eta_{00}$. The current experimental situation is summarized in Table 1. It is worth to notice that the test of CPT conservation based on the comparison of the K^0 and $\overline{K^0}$ masses is currently limited by the poor knowledge of η_{000} [4].

During the year 2000, NA48 did not have drift chambers because they were damaged by the implosion of the carbon fiber beam pipe. So we exploited the excellent energy resolution of a liquid krypton calorimeter (LKr) [10] to collect $3\pi^0$ decays from a long and a short neutral beam to improve the limits on η_{000}. The sensitivity to η_{000} comes from the $K_S - K_L$ interference that can be measured studying the intensity of $3\pi^0$ decays in the short neutral beam as a function of the proper decay time of the kaon. In order to keep the acceptance correction under control, the data were normalized using $3\pi^0$ decays collected from the long beam, which is a pure K_L beam for all practical purposes and where the $K_S - K_L$ interference expected in $3\pi^0$ decays is completely negligible. A Monte Carlo simulation was used to correct for the residual geometric difference between the two beams. An incoherent $K^0 - \overline{K}^0$ mixture is produced striking 450(400) GeV protons on a 40 cm long Be far(near) target placed 126(6) m upstream of the beginning of an evacuated decay region, respectively. Data were first collected from the far target for about one month and subsequently from the near target. The data taking conditions are summarized in Table 2. The trigger criteria and the detector conditions were kept the same during the far and near data taking period with the exception of the settings of the dipole magnet. This leads to a small correction acceptance for the $K_S \to \pi^0\pi^0\gamma e^+e^-$ decays. To minimize the effects due to accidental activity that may affect the reconstruction efficiency, the rate of a particle in the detectors was adjusted to be similar for the two data taking periods. The decay energy spectra of kaon generated from the near and far beam are not identical as one can see from Fig. 1. In order to take care of this difference, the analysis is done fitting the data in 5 GeV wide energy bins according to the function:

$$f(E,t) = \frac{\text{near}}{\text{far}} = A(E)[1 + |\eta_{000}|^2 e^{(\Gamma_L - \Gamma_S)t} +$$
$$+2D(E)e^{\frac{1}{2}(\Gamma_L - \Gamma_S)t} \times$$
$$\times (\text{Re } \eta_{000} \cos \Delta mt - \text{Im } \eta_{000} \sin \Delta mt)], \tag{1}$$

Table 1. Overview of current results

Experiment	Result
FNAL-E621 [5]	Im $\eta_{\pm 0} = -1.5 \pm 1.7 \pm 2.5 \times 10^{-2}$
CPLEAR [6]	Re $\eta_{\pm 0} = -2 \pm 7^{+4}_{-1} \times 10^{-3}$
	Im $\eta_{\pm 0} = -2 \pm 9^{+2}_{-1} \times 10^{-3}$
ITEP-761 [7]	Re $\eta_{000} = -8 \pm 18 \times 10^{-2}$
	Im $\eta_{000} = -5 \pm 27 \times 10^{-2}$
CPLEAR [8]	Re $\eta_{000} = 18 \pm 14 \pm 6 \times 10^{-2}$
	Im $\eta_{000} = 15 \pm 20 \pm 3 \times 10^{-2}$
SND [9]	BR($K_S \to 3\pi^0$) $< 1.4 \times 10^{-5}$ 90%CL

Table 2. Data taking conditions during the summer 2000

	Near	Far
Proton energy (GeV)	400	450
Production angle (mrad)	3.0	2.4
Beam length (m)	6	126
Dipole kick p_t MeV/c	0	265
Dates (Y2K)	30/5-2/7	13/7-30/8

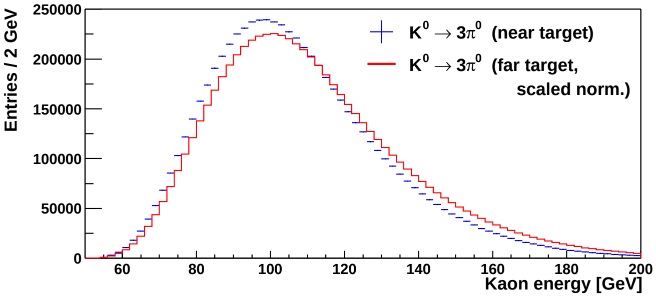

Fig. 1. Data from the near and far targets as a function of the kaon energy. The decay spectra are not identical and the fitting to extract η_{000} is done in energy bins to take this effect into account

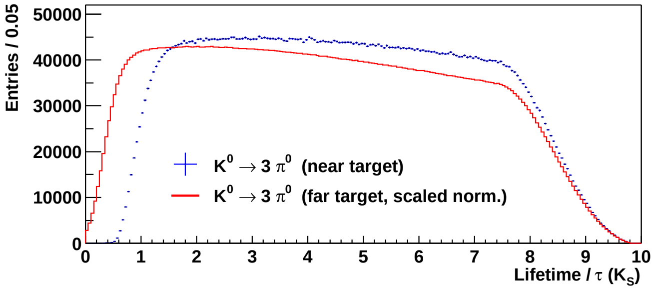

Fig. 2. Data from the near and far targets displayed as a function of reconstructed proper time before geometry correction and energy binning

where $A(E)$ are normalization constants and $D(E)$ is the so-called $K^0 - \overline{K}^0$ *dilution* describing the excess of produced K^0 over $\overline{K}^0$. $D(E)$ is a function of the energy and of the production angle. We use the dilution values measured by the NA31 experiment [11] slightly adjusting them to take into account the different production angle and proton energy.

The trigger required:

1. The total energy deposited in the LKr to be larger than 50 GeV.
2. The kaon center of gravity to lie within 15 cm from the beam axis.
3. The proper decay time computed from the exit of the collimator to be less than 9 K_S lifetimes.

In Fig. 1 the data are shown as a function of energy.

In Fig. 2, the data are displayed as a function of proper time before geometry correction and before dividing the data in energy bins. The trigger efficiency was measured reconstructing events triggered independently by a scintillating fiber hodoscope embedded in the LKr calorimeter. The trigger efficiency was found to be consistent for decays collected from both beams. Only data reconstructed at least 0.5 K_S lifetimes from the final collimator were fitted in order to avoid resolution effects. The downstream end of the fiducial region was chosen to limit the analysis to the region of good trigger efficiency (99.7%) and large event statistics. Data statistics amounts to about 5.6×10^6 $3\pi^0$ from the near beam and in excess of 10^7 from the far beam. The near/far ratio corrected for the beam geometry is shown in Fig. 3 for three energy bins. The position of the collimator and the upstream and downstream boundaries of the fitting region are indicated on the figure. Systematics errors have been evaluated for accidentals, energy scale, K^0 dilution, acceptance and binning and are reported in Table 3.

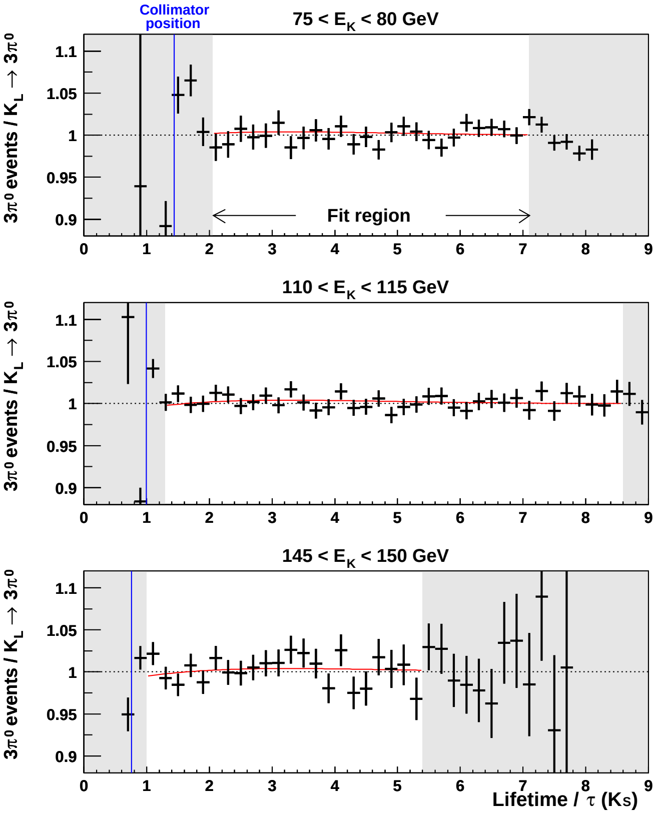

Fig. 3. Near/far ratio for three energy bins after geometry correction

Table 3. Systematic uncertainties

	Re $\eta_{000} (10^{-2})$	Im $\eta_{000} (10^{-2})$
Accidentals	±0.1	±0.6
Energy Scale	±0.1	±0.1
Dilution	±0.3	±0.4
Acceptance	±0.3	±0.8
Binning	±0.1	±0.2
Total	±0.5	±1.1

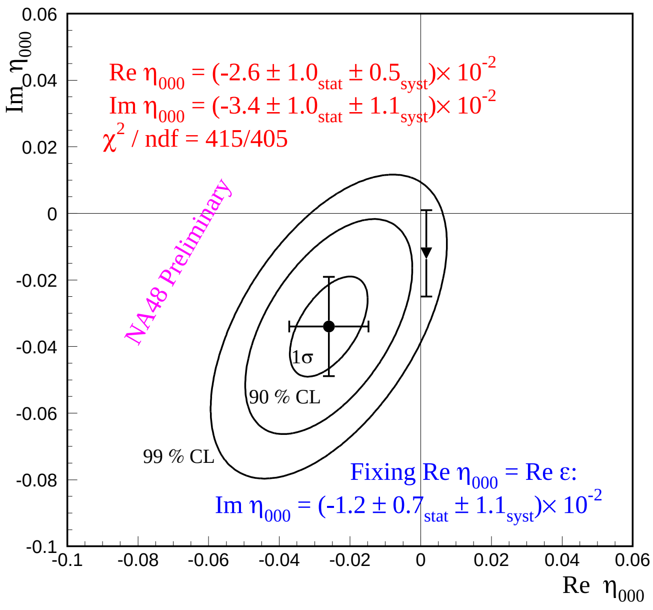

Fig. 4. Results of the fit

We have made two fits of Eq. (1):

1. The Real and the imaginary part of η_{000} are fitted independently together with the normalization constants. The results are:

$$\mathrm{Re}\ \eta_{000} = -2.6 \pm 1.0(\mathrm{stat.}) \pm 0.5(\mathrm{syst.}) \times 10^{-2}, \tag{2}$$

$$\mathrm{Im}\ \eta_{000} = -3.4 \pm 1.0(\mathrm{stat.}) \pm 1.0(\mathrm{syst.}) \times 10^{-2}. \tag{3}$$

   The χ^2/ndf is 415/4015 but the two parameters are strongly correlated ($\rho \simeq 0.8$). The fit is compatible with CP-conservation with a probability of a few %.

2. To avoid the correlation of the parameters, we have also imposed CP-conservation and fixed the real part of η_{000} to the SM prediction:

$$\mathrm{Re}\ \eta_{000} = \mathrm{Re}\ \epsilon \simeq 1.6 \times 10^{-3}. \tag{4}$$

   Fitting for Im η_{000} then yields

$$\mathrm{Im}\ \eta_{000} = -1.2 \pm 0.7(\mathrm{stat.}) \pm 1.1(\mathrm{syst.}) \times 10^{-2} \tag{5}$$

   which is compatible with CP-conservation within errors.

The result of the fits is shown in Fig. 4. Result (5) translates into the limit BR($K_S \to \pi^0\pi^0\pi^0$) $< 3.0 \times 10^{-7}$@90%CL which improves the current limit by about 50 times and is compatible with the SM prediction of $\sim 3 \times 10^{-9}$. Results (2) and (3) provide input to the Bell—Steinberger unitarity relation [12], which constrains the CP- and CPT-violating parameter Im δ under the hypothesis of conservation of the probability:

$$\mathrm{Re}\ \epsilon - i\,\mathrm{Im}\ \delta = \frac{1}{2\left(i\Delta m + \frac{1}{2}\left(\Gamma_S + \Gamma_L\right)\right)} \times$$
$$\times \sum_f A(K_S \to f)^* A(K_L \to f). \tag{6}$$

Taking into account the NA48 result, we obtain

$$\mathrm{Im}\ \delta = (-1.2 \pm 3.0) \times 10^{-5}, \tag{7}$$

which represents an improvement of about 40% with respect to the previous result:

$$\mathrm{Im}\ \delta = (2.4 \pm 5.0) \times 10^{-5}\ [13]. \tag{8}$$

Assuming CPT-conservation in the semi-leptonic K^0 decays, the phase of δ is fixed and the measurement translates into a new limit on the $K^0\overline{K}^0$ mass difference:

$$M_K^0 - M_{\overline{K}^0} = (-1.7 \pm 4.2) \times 10^{-19}\ \mathrm{GeV} \tag{9}$$

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ПОШУК CP-ПОРУШЕННЯ В РОЗПАДАХ $K_S \to \pi^0\pi^0\pi^0$

А. Чеккучі

Резюме

Протягом 2000 року проводилися експерименти з пошуку CP-порушення в розпадах $K_S \to \pi^0\pi^0\pi^0$, використовуючи дані, зібрані на короткому нейтральному пучку на прискорювачі SPS в ЦЕРНі. В даній роботі представлено нові границі для параметра CP-порушення η_{000} та BR ($K_S \to \pi^0\pi^0\pi^0$). Використовуючи унітарне співвідношення Бела — Стейнберга, похибку у визначенні в параметрів CP-порушення та CPT-порушення Im δ було зменшено, що привело до надійнішої перевірки CPT-збереження: різницю мас K^0 і $\overline{K}^0$ було знайдено як $\Delta M = (-1.7 \pm 4.2)^{-19}$ ГеВ.

ПОИСК CP-НАРУШЕНИЯ В РАСПАДАХ $K_S \to \pi^0\pi^0\pi^0$

А. Чеккучи

Резюме

На протяжении 2000 года проводился поиск CP-нарушения в распадах $K_S \to \pi^0\pi^0\pi^0$, используя данные, собранные на коротком нейтральном пучке на ускорителе SPS в ЦЕРНе. В данной статье представлены новые пределы для параметра CP-нарушения η_{000} и BR ($K_S \to \pi^0\pi^0\pi^0$). Используя унитарное соотношение Белла — Стейнберга, погрешность определения параметров CP-нарушения и CPT-нарушения Im δ была уменьшена, что привело к улучшенной проверке CPT-сохранения: разница масс K^0 и $\overline{K}^0$ найдена как $\Delta M = (-1.7 \pm 4.2)^{-19}$ ГэВ.